

FM Subcarrier Corridor Assessment for the Intelligent Transportation System

Robert O. DeBolt
Nicholas DeMinco



report series

U.S. DEPARTMENT OF COMMERCE • National Telecommunications and Information Administration



FM Subcarrier Corridor Assessment for the Intelligent Transportation System

**Robert O. DeBolt
Nicholas DeMinco**



**U.S. DEPARTMENT OF COMMERCE
Mickey Kantor, Secretary**

Larry Irving, Assistant Secretary
for Communications and Information

January 1997

PREFACE

The propagation studies and analysis described in this report were sponsored by the Federal Highway Administration (FHWA), U.S. Department of Transportation, McLean, Virginia. The guidance and advice provided by J. Arnold of FHWA are gratefully acknowledged.

CONTENTS

| | Page |
|--|------|
| 1. INTRODUCTION. | 1 |
| 1.1 Background..... | 1 |
| 1.2 Objective..... | 2 |
| 1.3 Study Tasks. | .3 |
| 1.4 Study Approach. | .3 |
| 1.5 FM Subcarrier Systems. | .4 |
| 2. ANALYSIS OF CORRIDOR 1 - Interstate 95 from Richmond, Virginia, to Portland, Maine. | 5 |
| 3. ANALYSIS OF CORRIDOR 2 - Gary, Indiana, to Chicago, Illinois, and Milwaukee, Wisconsin, along Interstates 80, 90, and 94. | 7 |
| 4. ANALYSIS OF CORRIDOR 3 - The Atlanta, Georgia, Metropolitan Area.. | 8 |
| 5. CONCLUSIONS..... | 9 |
| 6. REFERENCES..... | 20 |
| APPENDIX: COMMUNICATION SYSTEM PERFORMANCE MODEL | 21 |

FM SUBCARRIER CORRIDOR ASSESSMENT FOR THE INTELLIGENT TRANSPORTATION SYSTEM

Robert O. DeBolt and Nick DeMinco*

This report documents the assessment of FM subcarrier performance for Intelligent Transportation Systems (ITS) applications in three areas of interest in the United States. These areas are: 1) The Interstate 95 corridor from Richmond, Virginia, to Portland, Maine; 2) The Midwest corridor from Gary, Indiana, to Chicago, Illinois, and Milwaukee, Wisconsin, along Interstates 80, 90, and 94; and 3) The Atlanta, Georgia, Metropolitan Area. This study indicates that subcarrier systems of carefully chosen FM stations can provide good performance for ITS applications.

Key words: FM subcarrier; Intelligent Transportation System; ITS; IVHS

1. INTRODUCTION

The Federal Highway Administration (FHWA) provided funding to the MITRE Corporation to investigate the use of FM subcarriers for the broadcast of traffic data to vehicles on highways to support the Intelligent Transportation System (ITS) program. In response to this contract, MITRE developed the prototype hardware called the Subcarrier Traffic Information Channel (STIC) System. The National Telecommunications and Information Administration/Institute for Telecommunication Sciences (NTIA/ITS) independently evaluated, both in the laboratory and in the field, the performance of an FM subcarrier-based traveler information broadcast system. This report describes the results of the FM subcarrier coverage predictions for three areas in the United States. The geographic plots of the areas of coverage by the FM subcarrier systems are presented along with descriptions of potential problem areas with this approach to the traveler information system services for ITS.

1.1 Background

The United States Department of Transportation (DOT) established the ITS program to use advanced computer, electronics, and communications technologies to improve the effectiveness of the nation's highway system. ITS uses these technologies to provide a group of functions that include information processing, navigation, communications, and control. Once it is fully functional, ITS will provide information to travelers about road and transit

*The authors are with the Institute for Telecommunication Sciences, National Telecommunications and Information Administration, U.S. Department of Commerce, Boulder, CO 80303.

travel conditions and will monitor, guide, and assist in the control and operation of vehicles. ITS can enable travelers to make more informed choices about routes, times, and modes of travel. It will also allow authorities to manage transportation systems and control traffic more efficiently. Authorities will be able to respond rapidly to road accidents to restore traffic flow, redirect traffic away from the most congested routes, provide informational ridesharing, control traffic at intersections and on street networks, meter ramps on freeways, reserve lanes for buses and high-occupancy vehicles, and provide automatic in-transit commercial vehicle weigh-in and toll collection. In the future, ITS will assist drivers and reduce accidents through automation of vehicle control.

A potential method for providing traveler information services in some demonstration projects and possibly the final ITS architecture is via an FM subcarrier on an existing channel of the FM broadcast band. FM subcarriers have long been used for a variety of applications. More recently, FM subcarriers have been used to transmit road warnings and conditions, traveler advisories, emergency situations, and navigation information; these ITS applications have shown great promise.

NTIA/ITS developed computer programs to assist in the assessment of FM subcarrier performance for ITS applications. These programs assist the engineer in choosing the best FM stations that could provide subcarrier coverage over a desired corridor by predicting the area coverage of stations deploying ITS subcarrier systems.

NTIA/ITS also measured the STIC system performance when installed in the subcarrier channel of a commercial FM broadcast station. STIC performance was evaluated in a variety of reception environments in order to assist in the verification of the prediction of subcarrier coverage in three specific areas of the United States that differ dramatically in terrain and population density. These regions may implement the FM subcarrier form of Advanced Traveler Information System (ATIS). The primary goal of the field test program was to correlate the STIC performance with received signal level in a variety of reception environments. The test results were used to establish a threshold for minimum detectable signal in a variety of propagation environments and then verify the coverage predictions that were made. After these thresholds for acceptable performance were established, reliable predictions were made for other areas of the country.

1.2 Objective

The objective of this study was to evaluate the area coverage capabilities of FM stations that may be used in ITS applications in three areas of the United States and determine if a particular set of FM stations could provide adequate subcarrier coverage for ITS applications.

This assessment focused on three areas of the United States: 1) The Interstate 95 corridor from Richmond, Virginia, to Portland, Maine; 2) The Midwest corridor from Gary, Indiana, to Chicago, Illinois, and Milwaukee, Wisconsin, along Interstates 80, 90, and 94; and 3) The Atlanta, Georgia, Metropolitan area.

1.3 Study Tasks

The assessment study incorporated the following tasks:

- 1) Define the corridor bounds and extract reference points from within these bounds. These include points along interstate highways and points around major metropolitan areas that define the analysis area. These points were chosen to be at approximately 1 -km intervals along interstates and within 80 km of the center of downtown Atlanta for corridor 3.
- 2) Search through the Federal Communications Commission (FCC) FM database to extract those stations within a specified distance from the reference points determined above.
- 3) Import the selected set of FM stations into the Communication System Performance Model (CSPM) to predict the FM subcarrier coverage for each station. For a description of the CSPM program, see Appendix A.
- 4) Evaluate the coverage for each station to determine if the coverage is insufficient or redundant. Develop a set of stations that could provide the desired coverage most efficiently. This selection was based upon location and power only. Cost and contractual arrangements were not considered.
- 5) Produce a composite coverage map of the selected corridors using this chosen set of FM stations.

1.4 Study Approach

The Telecommunications Analysis Services Group of NTIA/ITS developed software and databases that provide users with the means to find, extract, and analyze FM station parameters and performance. This software was used to develop new software that allows the ITS user to specify a geographic block by latitude and longitude and a target interstate highway or city within that block. These programs extract reference points for this target area, search the FCC FM database, extract all FM stations within a specified distance from the targets, and import these FM stations and their equipment parameters into the CSPM program.

The results of the CSPM analyses can then be examined to determine the quality of coverage of the target area for each FM station. Those that provide poor coverage or redundant coverage are removed from the set of “best” stations leaving a minimum set of FM stations that can provide the desired target coverage. The coverage of these FM stations are combined to produce a composite coverage map of the target area.

1.5 FM Subcarrier Systems

The STIC system is a proof-of-concept prototype developed by the MITRE Corporation under the sponsorship of the ITS program. The prototype is intended to demonstrate the ability to broadcast high-speed digital data using the existing commercial FM broadcast radio infrastructure.

The STIC system is an FM subcarrier-based data transmission and reception system. It is designed to achieve reliable communications in the multipath and fading environment associated with very high frequency (VHF) mobile receivers. To achieve that end, the STIC system uses high levels of signal processing and error correction. The key characteristics of the waveform are:

- 72.2-kHz center frequency;
- 20-kHz bandwidth;
- x/4 DQPSK with square root raised cosine filtering;
- %-rate convolutional code (to mitigate random errors);
- Reed-Solomon (228,243) block code (to provide error detection and mitigate errors);
- convolutional interleaving (to randomize burst errors); and
- 18.05-kbps channel data rate and >8-kbps information data rate.

The prototype STIC system consists of a transmitter subsystem and receiver subsystem. The STIC transmitter subsystem consists of the STIC subcarrier generator and a personal computer (PC). The PC is used to control and configure the subcarrier generator and generate messages for transmission. The subcarrier generator is enclosed in a single rack-mounted chassis. It connects directly to the subcarrier input port of an FM broadcast exciter. The STIC receiver subsystem consists of an FM car stereo receiver (modified to demodulate the subcarrier signal), a Global Positioning System (GPS) antenna, the STIC receiver (which also functions as a GPS receiver), a hand-held data terminal, a data collection PC, and the STIC power supply and harness.

Coverage predictions were made for two different FM subcarrier systems: the FM Subcarrier Traffic Information Channel System and the Radio Broadcast Data System (RBDS). It was first necessary to determine the operating threshold of these systems. The operating threshold is the minimum field strength at the receiver required for operation.

The signal thresholds, which gave a specified level of performance for the STIC system, were determined from a measurement task "FM Subcarrier Coverage Measurement and Verification," also performed for the Federal Highway Administration. The results of the measurement task will be included in an NTIA/ITS report [1]. Two operating thresholds were used to characterize different propagation environments. The rural plains environment was characterized as an area having few significant natural or man-made obstacles and having virtually line-of-sight propagation paths. The urban low-rise environment was characterized as an area having significant man-made obstacles and obstructions typically one or two stories tall. The urban high-rise environment was characterized as an area typical of the downtown portion of a large city: city streets and urban canyons formed by long rows of buildings greater than two stories including high-rise buildings. An operating threshold

for the rural and urban low-rise environments was determined by measurement to be 54 dBuV/m. The operating threshold for the urban high-rise environment was determined by measurement to be 74 dBuV/m.

The operating thresholds for the RBDS were determined from [2], which contains an exhaustive description of the testing of the Radio Data System (RDS) in Europe; this system is very similar to the RBDS used in the United States. An operating threshold of 60 dBuV/m for an urban high-rise environment was obtained from [2]. An operating threshold of 29 dBuV/m was obtained from [3] for the rural and urban low-rise environment.

2. ANALYSIS OF CORRIDOR 1 Interstate 95 from Richmond, Virginia, to Portland, Maine

The analysis area was bounded by a rectangle whose north and west boundaries were 41 degrees 15 minutes north, 78 degrees 30 minutes west and whose south and east boundaries were 36 degrees 45 minutes north, 73 degrees west.

Reference points along Interstate 95 were extracted from the U.S. Geological Survey digital database of interstates. The FCC FM database was searched to select those FM stations within 80 km of each of these reference points. The list of candidate FM stations is shown in Table 1.

The area coverage for each of the stations listed in Table 1 was predicted using the CSPM model. To predict STIC reception, the operating thresholds of 74 dBuV/m for urban high-rise areas and 54 dBuV/m for urban low-rise areas were plotted by the CSPM. To predict RBDS reception, the operating thresholds of 60 dBuV/m for urban high-rise areas and 29 dBuV/m for urban low-rise areas were plotted by the CSPM. The results of these CSPM analyses were then visually examined to determine a minimum set of stations to cover this corridor. The selected set of stations was based upon location and power. Those stations that had the maximum amount of predicted coverage along the corridor were selected. Those stations that provided either minimal coverage along the interstate or that provided redundant coverage with one of the selected stations were not selected. The selected set of stations is shown in Table 2.

The coverage plots for the selected stations in Table 2 were then combined to produce the coverage composites shown in Figures 1 and 2. This analysis, and Figure 1 showed that in the case of predicted STIC coverage, there is a section of Interstate 95 in southeast Connecticut that has adequate urban low-rise coverage but inadequate urban high-rise coverage. Since this area of Connecticut is urban low-rise in nature, subcarrier coverage is adequate in this area. Predictions indicate that RBDS coverage would be adequate for the entire corridor.

Table 1. FM Stations within 80 km of Interstate 95

| | | | | | | | | |
|----------|--------|--------|--------|--------|--------|--------|--------|--------|
| WVST | WETA | WWMX | WBLS | WRTN | WCHR | WFLN | WQGN | WMPG |
| WKHK | WAVA | WERQ | WQHT | WRRH | WWFM | W204AD | WBMW | WMGX |
| WDYL | WGMS | WQSR | WNCN | WFAS | WTSR | W300AD | WTYD | WBQQ |
| WRVQ | WAMU | WEAA | WBAI | WXPS | WRRC | WMMR | WERS | WZZE |
| WVGO | WMMJ | WBJC | WPLJ | WEDW | W220AG | WKDN | WCTK | WCME |
| WMXB | WPFW | WXVY | WMXV | WKHL | WNJTFM | WEEE | WNYE | WPORFM |
| WHCE | WKYS | WTMD | WHTZ | W211AI | WKX | WFM | WKDU | WRQX |
| W22 1 AA | WWDC | WKJY | WPOB | WMGQ | WEAZ | WJBRFM | WCVE | WKHS |
| WXZL | WSKQF | W216AV | WPRB | WPEB | WTVR | WHUR | WNEW | WWDB |
| WARY | WVPH | WHHS | WDCE | WJZE | WLIF | WXRK | WRPR | WDVR |
| WXYU | WRXL | WASH | WBSB | WQXR | WNYK | WCVH | WYBF | WCDX |
| WFME | WDCU | WHFC | WRKS | WOSS | W289AA | WDBK | WYFJ | WGLSFM |
| WXCY | WCBS | WVIP | WNTI | WRSD | WPLC | WLTT | WGRX | WGAY |
| WLTW | W232AL | WRDV | WSRN | WJYJ | WMUC | WRCY | WDRE | WKNJ |
| WBJB | WBMR | WKSZ | WRTI | WFLS | WGTS | WKRB | WMNJ | WFSI |
| WCNJ | WEGX | WDNR | WBQB | WHFS | WSIA | WFMU | W220AA | W221AH |
| WLSA | WSMD | WNYE | WKWZ | WVHP | WMGK | WSTW | W280CP | WLIU |
| WGRQ | WMJS | WQCD | WCWP | WVPH | WXTU | WMPH | WDHAFM | WCSD |
| WCUL | WACC | WKCR | WHCR | WAWZ | WIBF | WVLT | WNYUFM | WNPR |
| WQRA | WINFM | WPAT | WJSV | WHTG | WHYY | WHEB | WEDW | WKCI |
| WPLZ | WRBS | WNYC | WHPH | WMCX | WYSP | WNNN | WNPR | WHYR |
| WDCK | WPOC | WYNY | W276AQ | WZVU | WYXR | WVUD | WXTR | W261CD |
| WRHU | WBGD | WDAS | WPGC | WBYQ | WBAU | WADB | WUSL | WCXR |
| WHPS | WHPC | WFUV | WJLK | WOGI | WOELFM | WJFK | WJHU | WBGD |
| W244AS | WMSC | WPST | WXPB | WDAC | WMZQ | WIYY | WSOU | WFDU |
| WIOQ | WHJY | WHRB | WHTZ | WKHL | WPLR | WVVE | WSVSFM | WBRU |
| WICN | WSKQ | WFX | WKSS | WSNE | WSSH | WNEW | WEBE | WYSR |
| WWBB | WXLO | WXRK | WWEM | WPKT | WPLM | WLYT | WQXR | WHUD |
| WZMX | WHUS | WKCR | WGBH | WZEA | WRKS | WMNR | WWYZ | WWRX |
| WMEA | WCDJ | WERZ | WCBS | WPKN | WDRC | WBLQ | WBLM | WBOS |
| WPAT | WLTW | WSHU | WHCN | WPJB | WTHT | WBMX | WNYC | WBAB |
| WEZN | WKJY | WRIU | WKZS | WODS | WYNY | WMJC | WALK | WIHS |
| WOTB | WCLZ | WBUR | WBGD | WOKQ | WRKI | WRCH | WPRO | WKRH |
| WCRB | WBLS | WFRS | WBLI | WWHB | WWLI | WXGL | WZLX | WQHT |
| WNYU | WNHU | WLNG | WMXV | WRTN | WMJV | WXS | WBAI | WFUV |
| WYBC | WBAZ | WQCD | WABK | WBCN | WPLJ | WUSB | WCQL | WHFM |
| WJFD | WKCG | WMJX | | | | | | |

Table 2. Selected FM Stations That Provide Maximum Coverage along Interstate 95

| | | | | | | | | |
|------|------|--------|------|------|------|------|------|------|
| WABK | WKRH | WCLZ | WPOR | WBQQ | WHEB | WLYT | WTYD | WBMW |
| WSSH | WGBH | WHJY | WPRO | WWRX | WVVE | WQGN | WJYJ | WKCI |
| WEBE | WKHL | WQCD | WMGQ | WAWZ | WKXW | WTVR | WWDB | WJBR |
| WXCY | WYOC | WI-IFS | WGAY | WBQB | WTVR | | | |

3. ANALYSIS OF CORRIDOR 2
Gary, Indiana, to Chicago, Illinois, and Milwaukee, Wisconsin, along
Interstates 80,90, and 94.

The analysis area was bounded by a rectangle whose north and west boundaries were 45 degrees north, 91 degrees 30 minutes west and whose south and east boundaries were 39 degrees, 30 minutes north, 84 degrees, 20 minutes west.

Reference points along Interstates 80,90, and 94 were extracted from the U.S. Geological Survey digital database of interstates. The FCC FM database was searched to select those FM stations within 80 km of each of these reference points. The list of candidate FM stations is shown in Table 3.

Table 3. FM Stations within 80 km of Interstates 80,90, and 94

| | | | | | | | | |
|------|------|------|-------|--------|------|------|------|------|
| WONU | WONC | WCRX | WKQX | WCBR | WHKQ | WFMR | WDND | WHSD |
| WCKG | WZVN | WYLL | WKKV | WTKM | WKBM | WDGC | WJMK | WGVE |
| WVWX | WMYX | WGLB | WBUS | WLTL | WTMX | WZRD | WMXM | WVCY |
| WBWI | WCFL | WDCB | WLSFM | WWJY | WEPS | WCCX | WIIL | WJCH |
| WETN | WLIT | WLUW | WABT | WHAD | WNIZ | WCCQ | WRSE | WBBM |
| WDSO | WXLC | WMSE | WSJY | WCSF | WKOT | WGCI | WVUR | WZSR |
| WLZR | WSUW | WLLI | WRKX | WNIB | WLJE | WDEK | WQFM | WJJO |
| WJTW | WSTQ | WPNT | WCOE | WDKB | WUWM | WMAD | WHFH | WKKC |
| WOJO | WEFM | WNIU | WMWK | WYKY | USN | WNTH | WBSD | WLTQ |
| WLRA | WCYC | WBEZ | WKVI | W289AB | WYMS | WXRO | WSPY | WMBI |
| WNUA | WGTC | WZOK | WZTR | WLRT | WXAV | WYCA | WXRT | WJKL |
| WQFL | WKTI | WTKC | WBHI | WRRG | WLUP | WMTH | WGSL | WEZW |
| WYSY | WSSD | WVAZ | WNUR | WXRX | WKLH | WHKD | WHPK | WFMT |
| WMWA | WGTD | WLUM | WARG | WOUI | | | | |

The area coverage for each of the stations listed in Table 3 was predicted using the CSPM model. To predict STIC reception, the operating thresholds of 74 dBuV/m for urban high-rise areas and 54 dBuV/m for urban low-rise areas were plotted by the CSPM model. To predict RBDS reception, the operating thresholds of 60 dBuV/m for urban high-rise areas and 29 dBuV/m for urban low-rise areas were plotted by the CSPM model. The results of these CSPM analyses were then visually examined to determine a minimum set of stations to cover this corridor. The selected set of stations was based upon location and power. Those stations that had the maximum amount of predicted coverage along the corridor were selected. Those stations that provided either minimal coverage along the Interstate or that provided redundant coverage with one of the selected stations were not selected. The selected set is shown in Table 4. This analysis indicated that there are more than enough stations to provide adequate coverage of the Interstates 80,90, and 94 corridor.

Table 4. Selected FM Stations that Provide Maximum Coverage along Interstates 80,90, and 94

WEFM WCOE WLJE WGVE WJMK WMBI WXLC WIIL WKKV WMYX WZTR

The coverage plots for the selected stations in Table 4 were then combined to produce the coverage composites shown in Figures 3 and 4. Both STIC and RBDS coverage predictions indicate that there would be adequate coverage for the entire corridor.

4. ANALYSIS OF CORRIDOR 3 The Atlanta, Georgia, Metropolitan Area

The city of Atlanta, Georgia, was the host of the 1996 Summer Olympic Games and FM subcarriers were used for facilitating traffic management during the Olympic Games. For this reason, Atlanta was chosen as corridor 3.

The analysis area was bounded by a rectangle whose north and west boundaries were 35 degrees north, 86 degrees west, and whose south and west boundaries were 32 degrees 30 minutes north, 82 degrees 30 minutes west.

A search of the FCC FM database was conducted to select those FM stations within 100 km of the city of Atlanta. The list of candidate FM stations is shown in Table 5.

Table 5. All FM Stations within 100 km of Atlanta, Georgia

WQUL WBTR WSTR WABE WALR WFOX WAFM WRAS WSB W22IAW WKHX
WYAY WCCV WJZF WCLK WVEE WKLS WGHR WGST WMKJ WGLSFM WREK
W298AA WPCH WYFW WWGC WZGC WNNX WLKQ WVEV WTSH W208AA WRFG

The area coverage for each of the stations listed in Table 5 was predicted using the CSPM model. To predict STIC reception, the operating thresholds of 74 dBuV/m for urban high-rise areas and 54 dBuV/m for urban low-rise areas were plotted by the CSPM model. To predict RBDS reception, the operating thresholds of 60 dBuV/m for urban high-rise areas and 29 dBuV/m for urban low-rise areas were plotted by the CSPM model. The results of these CSPM analyses were then visually examined to determine a minimum set of stations to cover the Atlanta area. The selected set of stations was based upon location and power. Those stations that had the maximum amount of predicted area coverage throughout Atlanta were selected. Those stations that provided either minimal coverage or that provided redundant coverage with one of the selected stations were not selected. The selected set is shown in Table 6.

Table 6. Selected FM Stations for Atlanta, Georgia

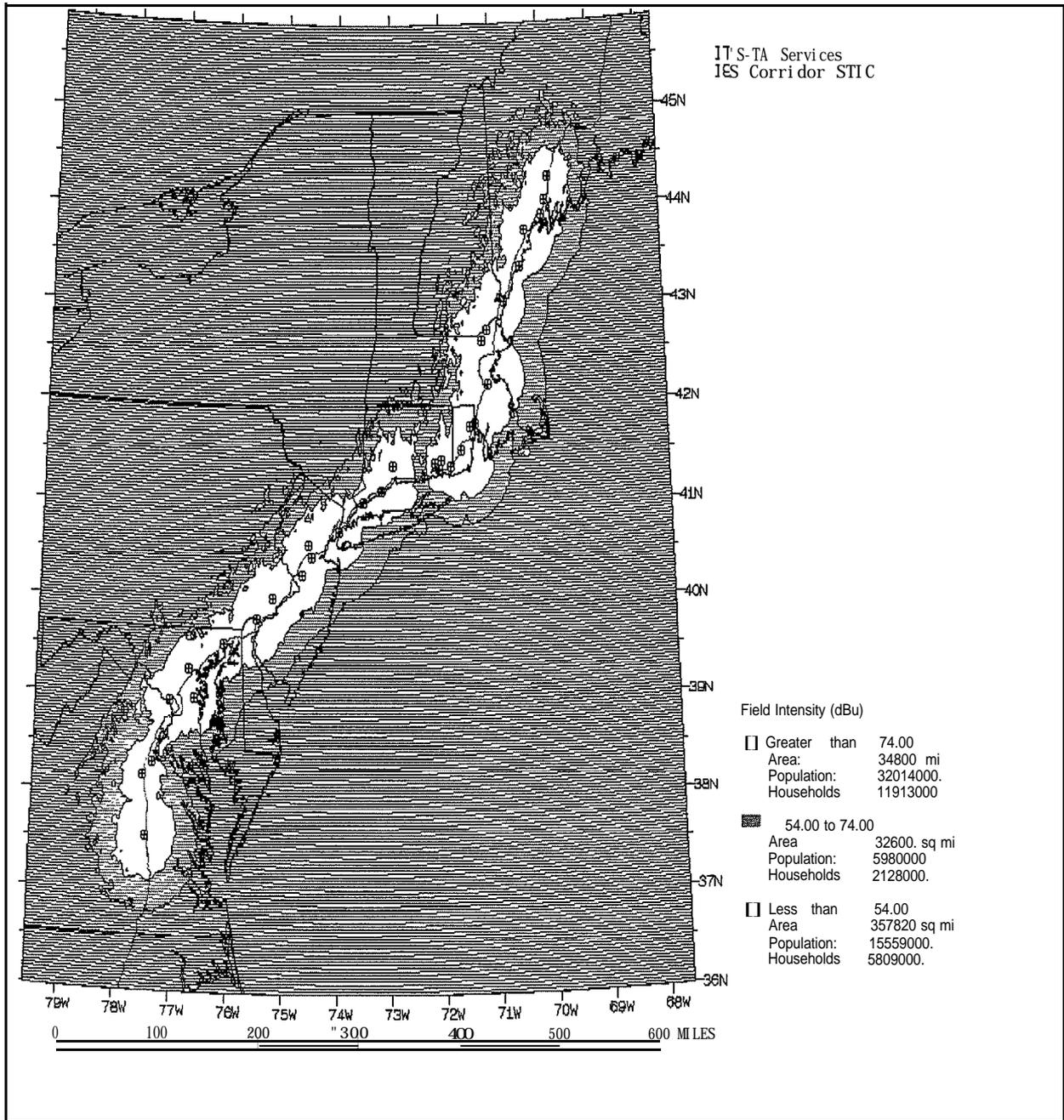
WWEV WTSH WGST WFOX WALR WNNX WJZF WQUL WJGA

The coverage plots for the selected stations in Table 6 were then combined to produce the coverage composites shown in Figures 5 and 6. Coverage predictions indicate that there would be adequate coverage for both STIC and RBDS systems.

There were two FM stations in the Atlanta area that are of particular interest since they were used in special coverage of the Olympic Games. These stations are WKLS and WRFG. Plots of the predicted STIC and RBDS coverage for each of these stations is shown in Figures 7 through 10.

5. CONCLUSIONS

Predictions indicate that both STIC and RBDS can provide good area coverage for ITS applications using the FM subcarriers of carefully chosen FM stations. STIC and RBDS coverage predictions shown in Figures 1 and 2 indicate that for the interstate corridor from Richmond, Virginia, to Portland, Maine, there is a section of Interstate 95 in southeast Connecticut that has adequate rural/urban low-rise STIC coverage but inadequate urban high-rise STIC coverage. Since this is a rural area of Connecticut, subcarrier coverage is adequate in this area. Predictions indicate that RBDS coverage would be adequate for the entire corridor. For the corridor from Gary, Indiana, to Chicago, Illinois, and Milwaukee, Wisconsin, along Interstates 80,90, and 94 (Figures 3 and 4), both STIC and RBDS coverage predictions indicate that there would be adequate coverage for the entire corridor. Figures 5 and 6 show the predicted STIC and RBDS coverage for the Atlanta area. Coverage predictions indicate that there would be adequate coverage for both STIC and RBDS systems. Figures 7 and 8 show the predicted STIC and RBDS coverage for station WKLS in Atlanta. These predictions indicate that there would be adequate coverage of the Atlanta area using WKLS from both STIC and RBDS systems. Figures 9 and 10 show the predicted STIC and RBDS coverage for station WRFG in Atlanta. These predictions indicate that there would be adequate coverage of the Atlanta area using WRFG, but that the coverage is not quite as good as that for station WKLS.



Environment

urban high-rise
urban low-rise
nonurban

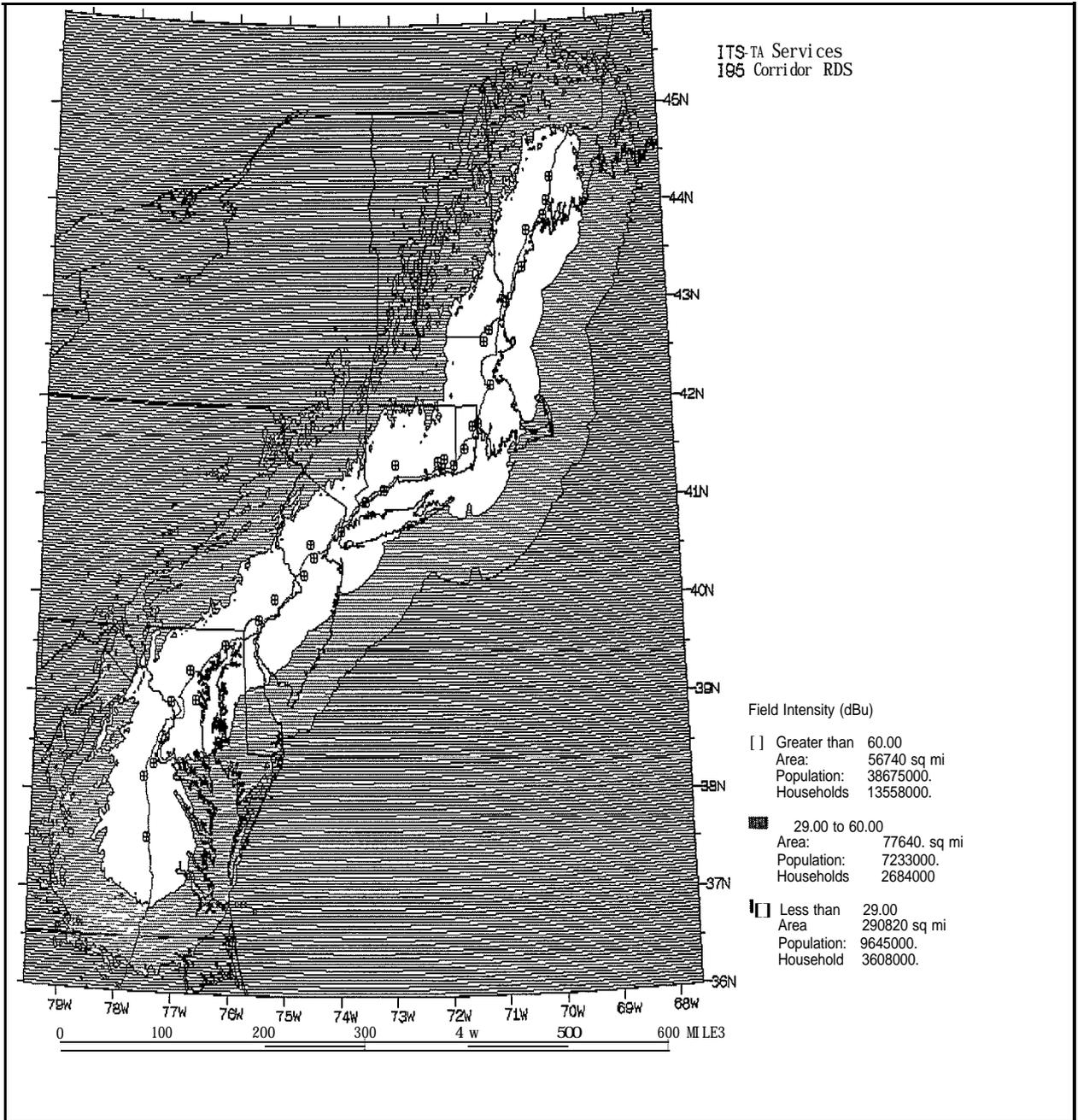
Threshold

(>74 dBu)
(54 - 74 dBu)
(< 54 dBu)
(note: 966 km = 600 mi)

Signal Coverage Area

90,178 sq km = 34,800 sq mi
84,477 sq km = 32,600 sq mi
927,224 sq km = 357,820 sq mi

Figure 1. Composite FM station STIC subcarrier coverage for corridor 1, Interstate 95.

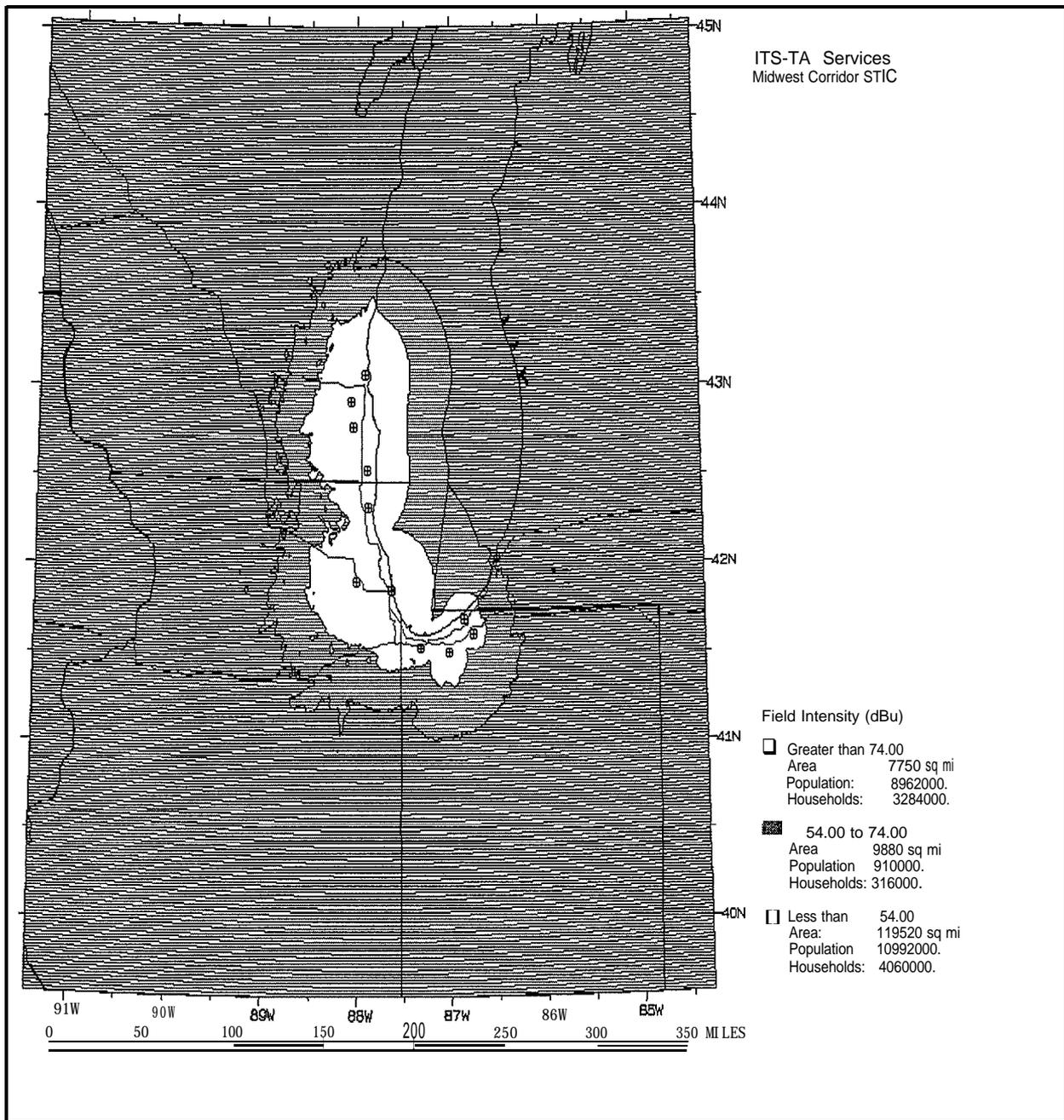


Environment
urban high-rise
urban low-rise
nonurban

Threshold
(>60 dBu)
(29 - 60 dBu)
(<29 dBu)
(note: 966 km = 600 mi)

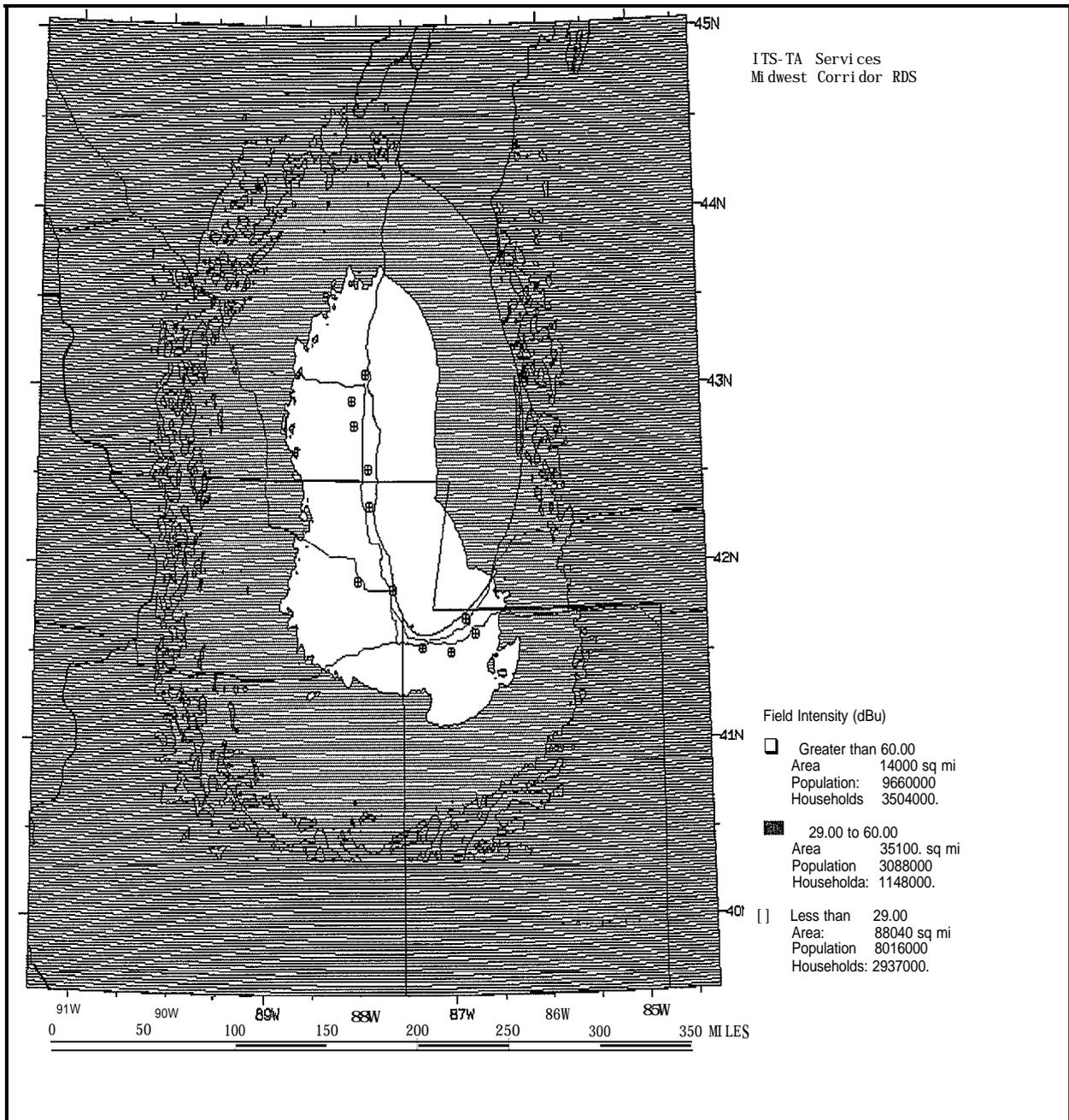
Signal Coverage Area
147,031 sq km = 56,740 sq mi
201,190 sq km=77,640sq mi
753,606 sq km = 290,820 sq mi

Figure 2. Composite FM station RBDS subcarrier coverage for corridor 1, Interstate 95.



| <u>Environment</u> | <u>Threshold</u> | <u>Signal Coverage Area</u> |
|--------------------|-------------------------|-------------------------------|
| urban high-rise | (>74 dBuV) | 20,083 sq km = 7,750 sq mi |
| urban low-rise | (54 - 74 dBuV) | 25,602 sq km = 9,880 sq mi |
| nonurban | (<54 dBuV) | 309,714 sq km = 119,520 sq mi |
| | (note: 563 km = 350 mi) | |

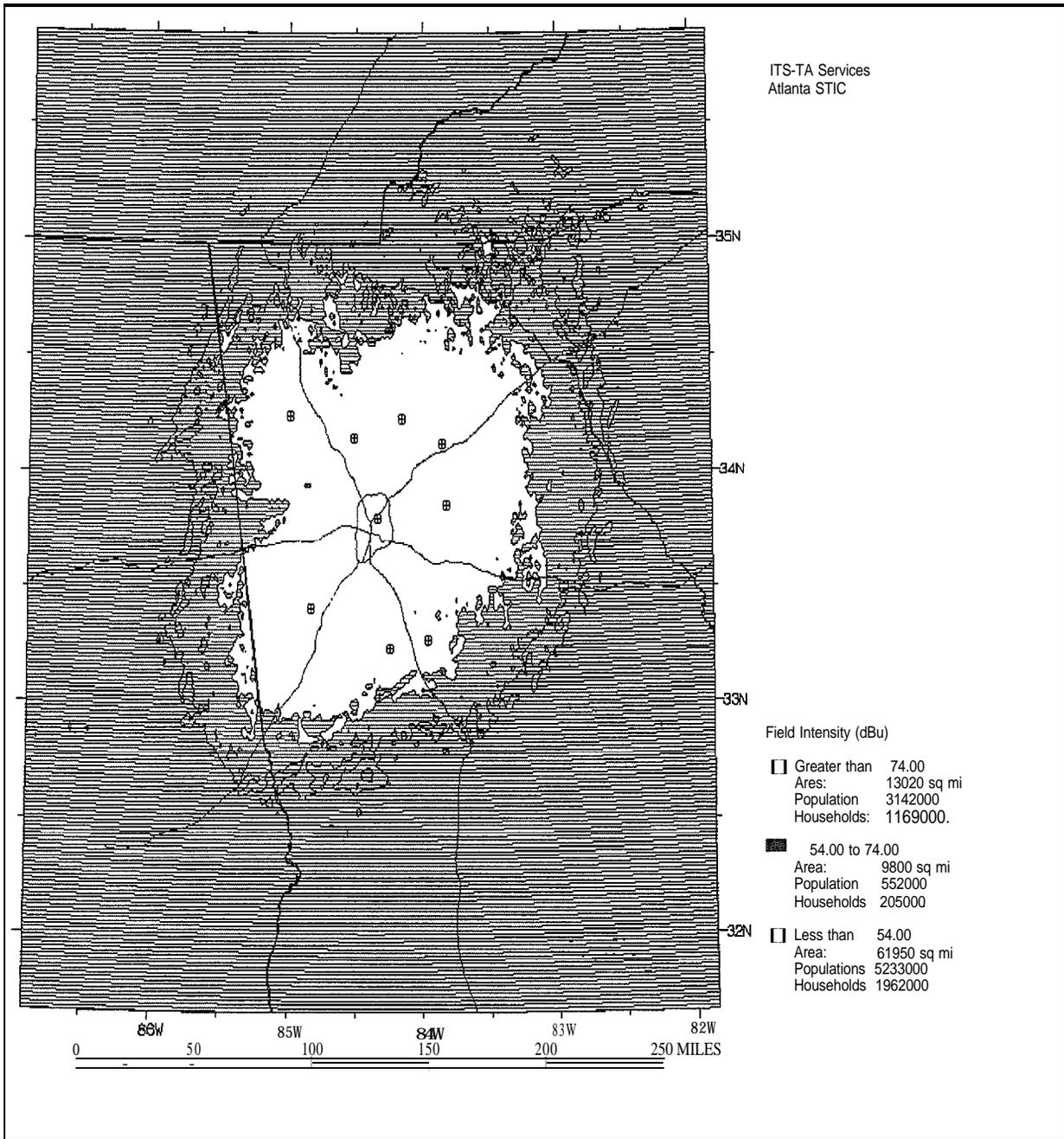
Figure 3. Composite FM station STIC subcarrier coverage for corridor 2, Midwest.



| <u>Environment</u> | <u>Threshold</u> | <u>Signal Coverage Area</u> |
|--------------------|------------------|------------------------------|
| urban high-rise | (>60 dBuV) | 36,278 sq km = 14,000 sq mi |
| urban low-rise | (29 - 60 dBuV) | 90,955 sq km = 35,100 sq mi |
| nonurban | (<29 dBuV) | 228,139 sq km = 88,040 sq mi |

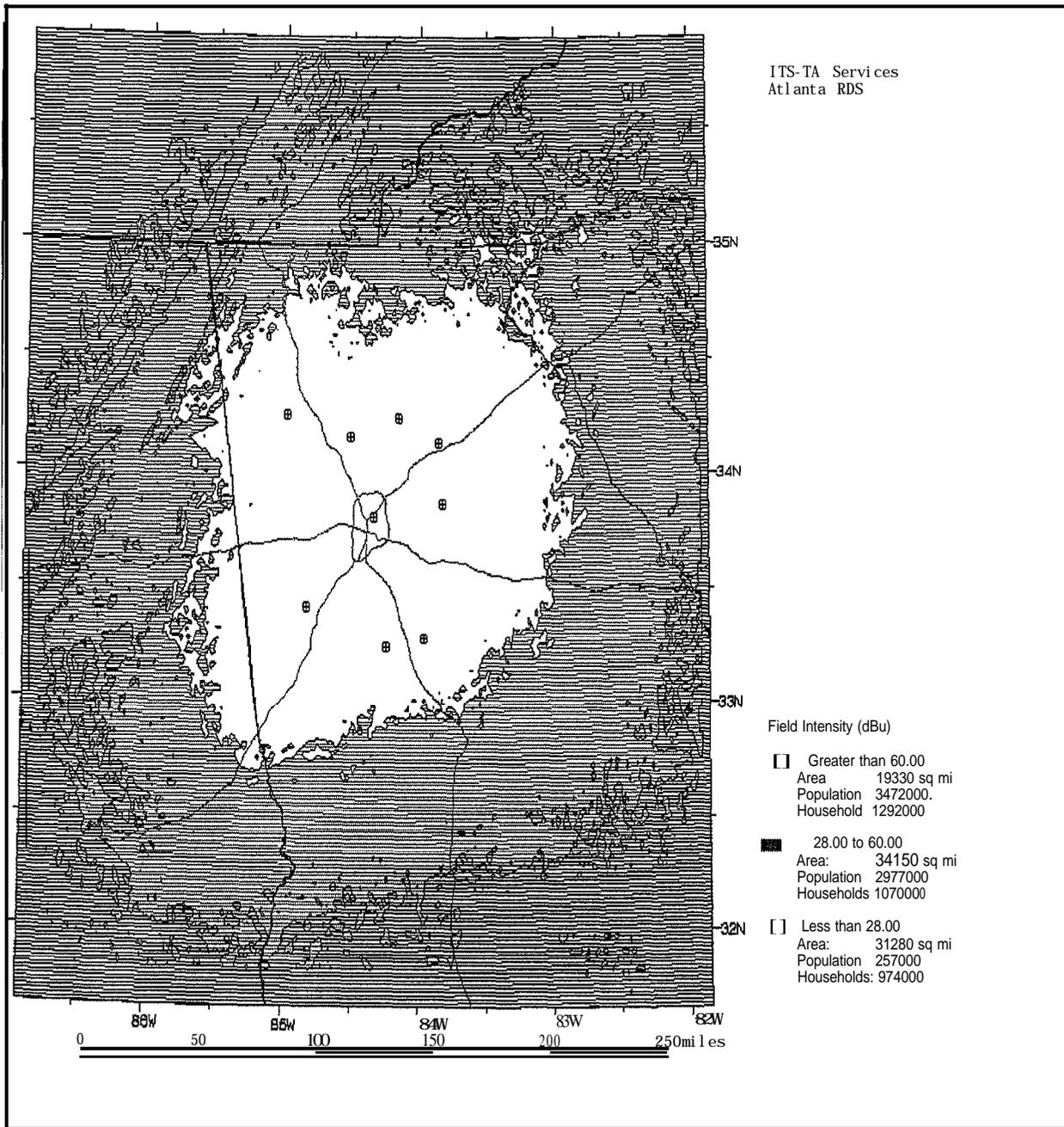
(note: 563 km = 88,040 sq mi)

Figure 4. Composite FM station RBDS subcarrier coverage for Corridor 2, Midwest.



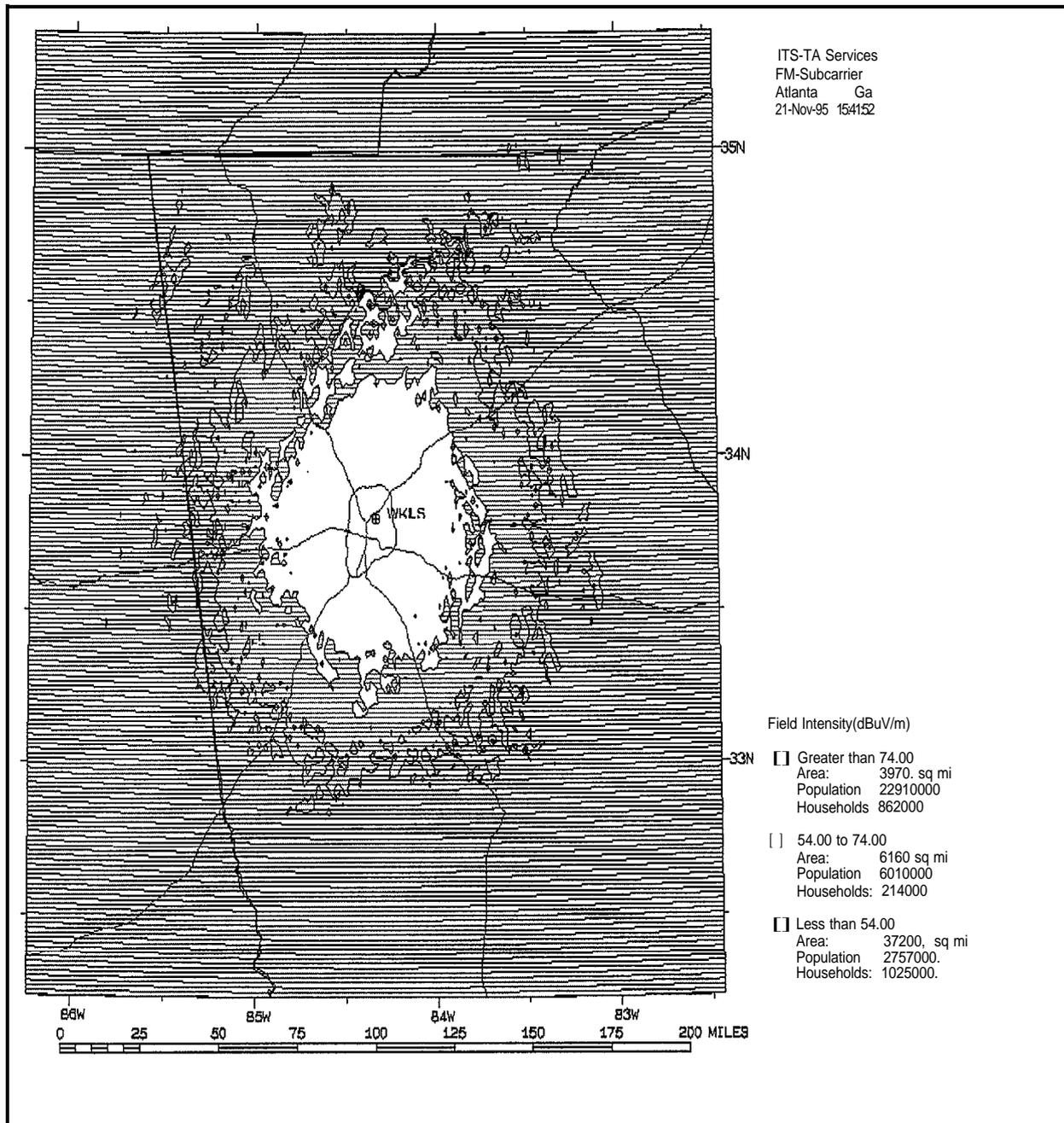
| <u>Environment</u> | <u>Threshold</u> | <u>Signal Coverage Area</u> |
|--------------------|-------------------------|------------------------------|
| urban high rise | (>74 dBuV) | 33,739 sq km = 13,020 sq mi |
| urban low rise | (54 - 74 dBuV) | 25,395 sq km = 9,800 sq mi |
| nonurban | (<54 dBuV) | 160,532 sq km = 61,950 sq mi |
| | (note: 402 km = 250 mi) | |

Figure 5. Composite FM station STIC subcarrier coverage for corridor 3, Atlanta.



| <u>Environment</u> | <u>Threshold :</u> | <u>Signal Coverage Area</u> |
|--------------------|-------------------------|-----------------------------|
| urban high-rise | (>60 dBuV) | 50,090 sq km = 19,330 sq mi |
| urban low-rise | (29 - 60 dBuV) | 88,493 sq km = 34,150 sq mi |
| nonurban | (<29 dBuV) | 81,056 sq km = 31,280 sq mi |
| | (note: 402 km = 250 mi) | |

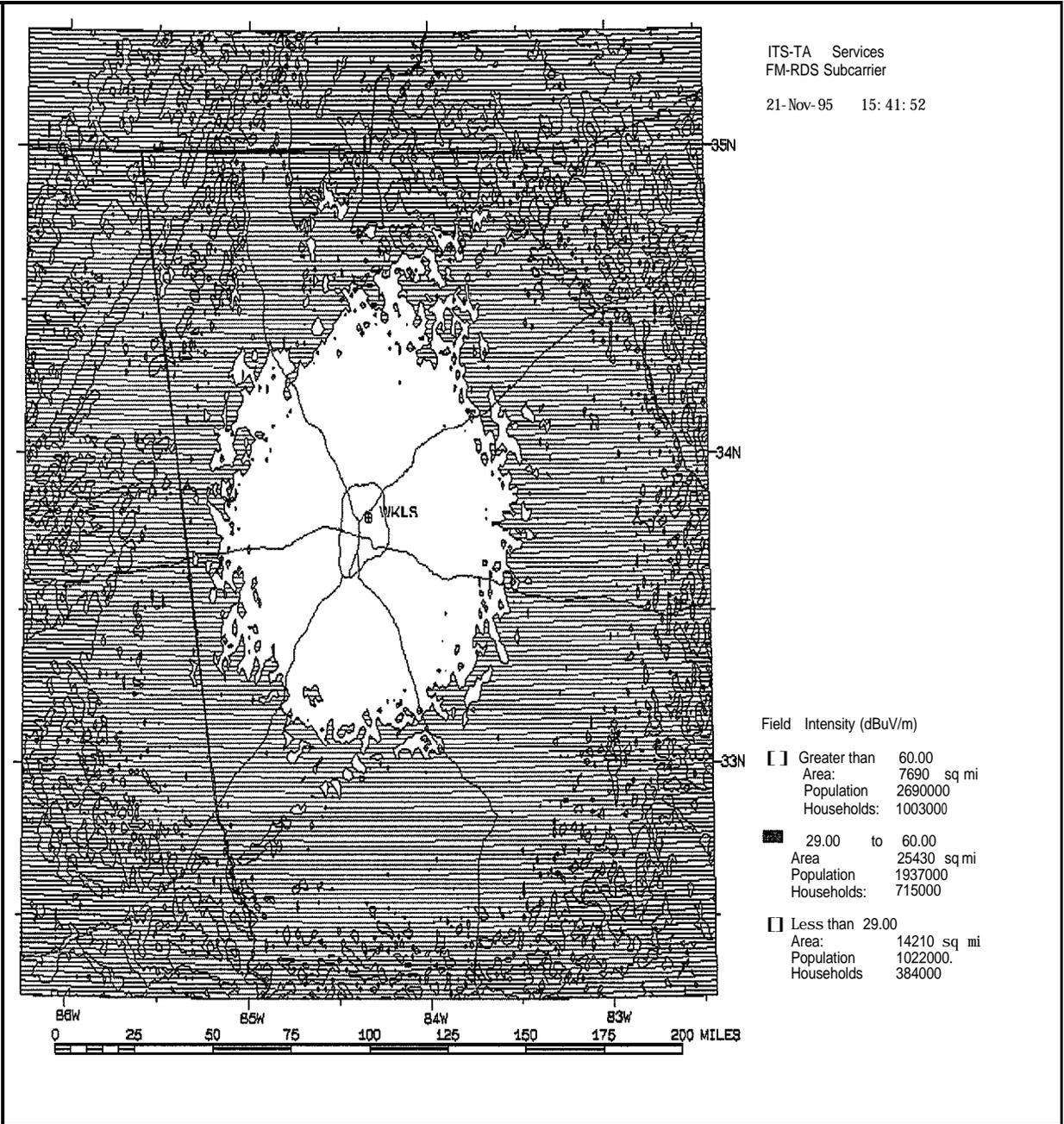
Figure 6. Composite FM station RBDS subcarrier coverage for corridor 3, Atlanta.



| <u>Environment</u> | <u>Threshold</u> | <u>Signal Coverage Area</u> |
|--------------------|------------------|-----------------------------|
| urban high-rise | (>74 dBuV) | 10,288 sq km = 3,970 sq mi |
| urban low-rise | (54 - 74 dBuV) | 15,962 sq km = 6,160 sq mi |
| nonurban | (<54 dBuV) | 96,397 sq km = 37,200 sq mi |

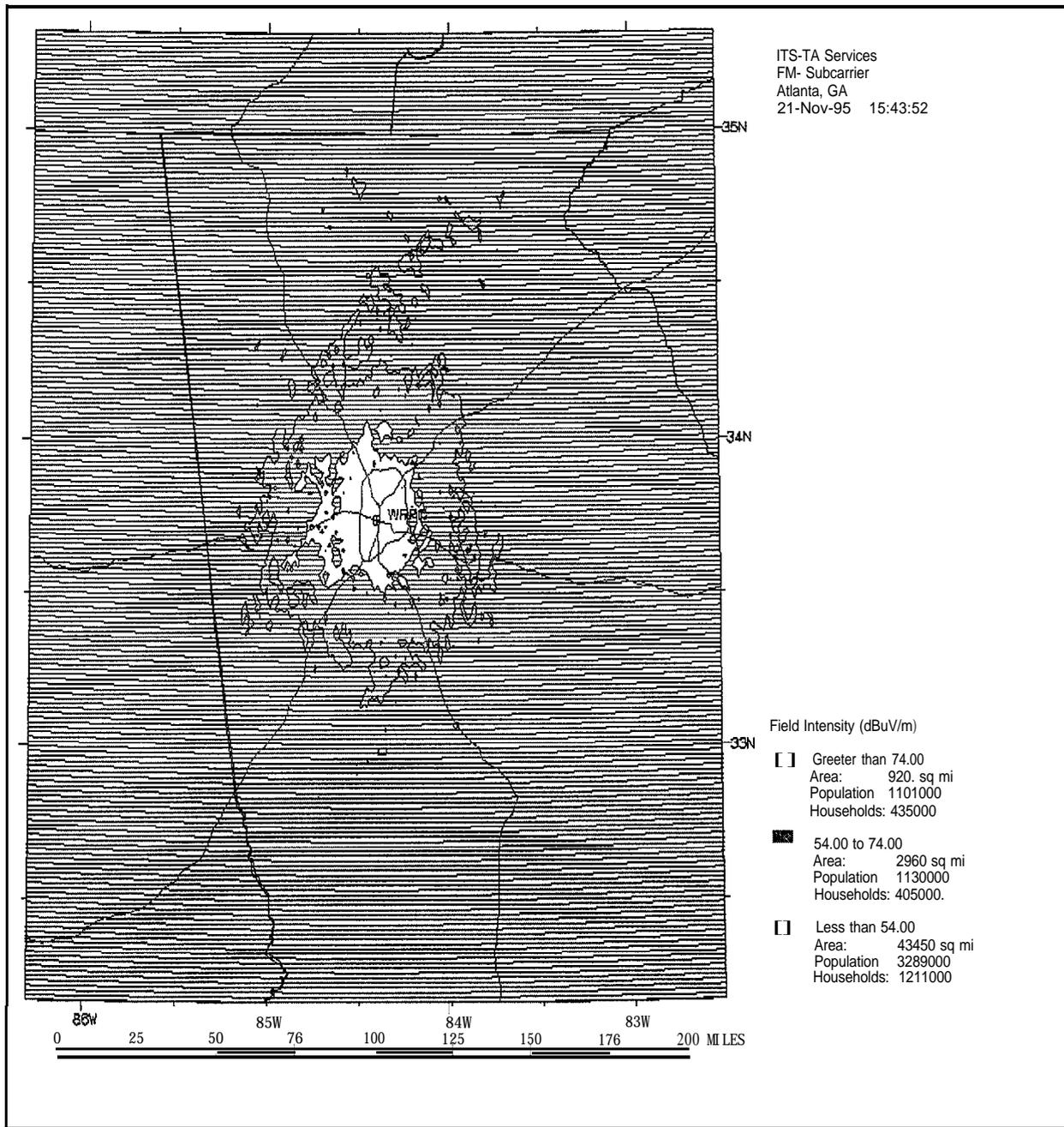
(note: 322 km = 200 mi)

Figure 7. WKLS FM station STIC subcarrier coverage for corridor 3, Atlanta.



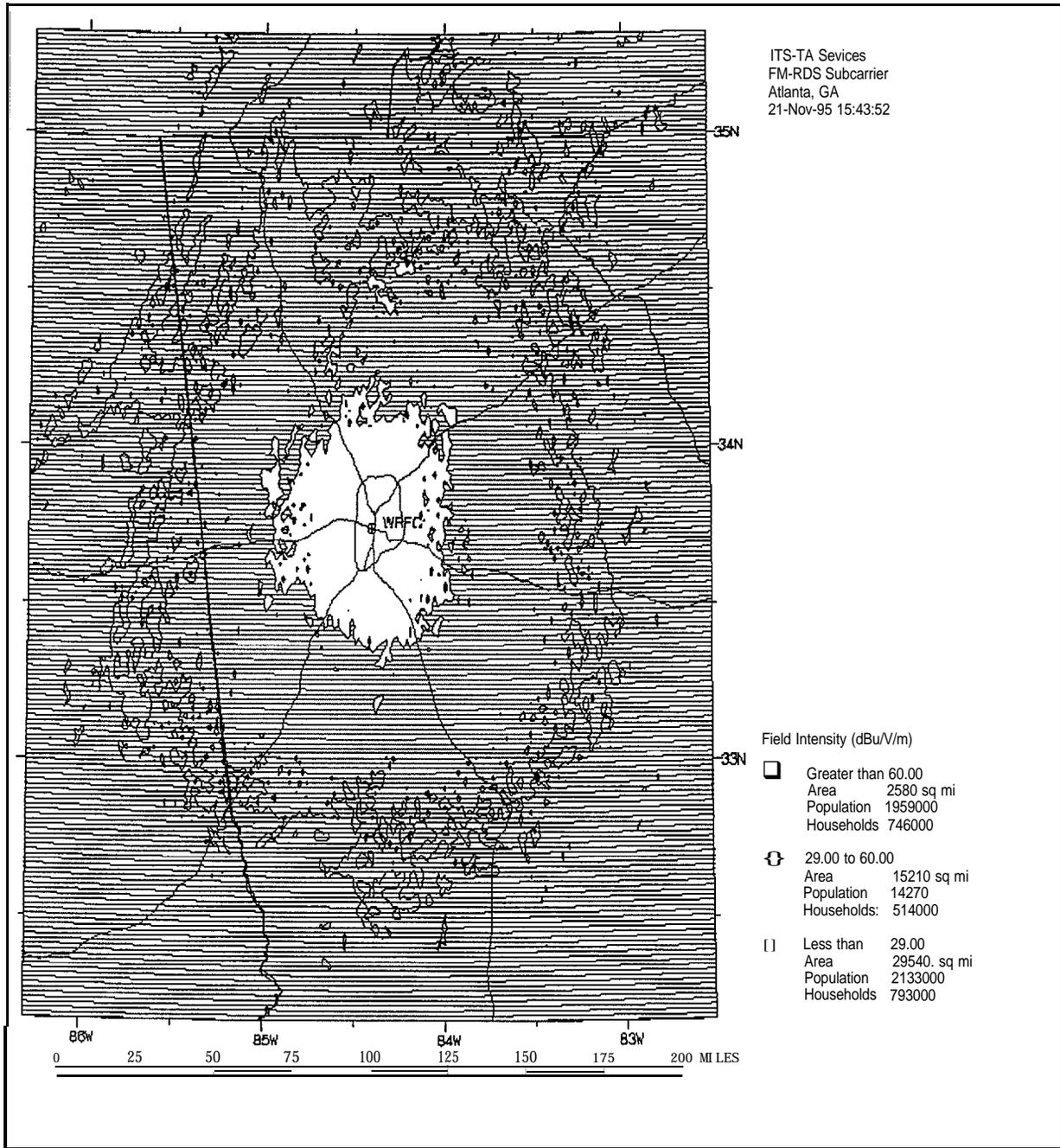
| <u>Environment</u> | <u>Threshold</u> | <u>Signal Coverage Area</u> |
|--------------------|-------------------------|-----------------------------|
| urban high-rise | (>60 dBuV) | 19,927 sq km = 7,690 sq mi |
| urban low-rise | (29 - 60 dBuV) | 65,897 sq km = 25,430 sq mi |
| nonurban | (<29 dBuV) | 36,823 sq km = 14,210 sq mi |
| | (note: 322 km = 200 mi) | |

Figure 8. WKLS FM station RBDS subcarrier coverage for corridor 3, Atlanta.



| <u>Environment</u> | <u>Threshold</u> | <u>Signal Coverage Area</u> |
|--------------------|-------------------------|------------------------------|
| urban high-rise | (>74 dBuV) | 2,384 sq km = 920 sq mi |
| urban low-rise | (54 - 74 dBuV) | 7,670 sq km = 2,960 sq mi |
| nonurban | (<54 dBuV) | 112,593 sq km = 43,450 sq mi |
| | (note: 322 km = 200 mi) | |

Figure 9. WRFG FM station STIC subcarrier coverage for corridor 3, Atlanta.



| <u>Environment</u> | <u>Threshold</u> | <u>Signal Coverage Area</u> |
|--------------------|------------------|-----------------------------|
| urban high-rise | (>60dBu) | 6,686 sq km = 2,580 sq mi |
| urban low-rise | (29-60 dBu) | 39,414 sq km = 15,210 sq mi |
| non-urban | (<29 dBu) | 76,547 sq km = 29,540 sq mi |

(note: 322 km = 200 mi)

Figure 10. WRFG FM station RBDS subcarrier coverage for corridor 3, Atlanta.

6. REFERENCES

- [1] J.F. Mastrangelo and W.R. Rust, "Subcarrier traffic information channel testing and evaluation, " NTIA Report 96-333, Jul. 1996.
- [2] G. Klein, "Digital traffic information using the radio data system," PhD Thesis, University of Nottingham, Nottingham, United Kingdom, pp. 170-209, May 1995.
- [3] International Telecommunications Union (ITU-R), "System for automatic tuning and other applications in FM radio receivers for use with the pilot-tone system," vol. X-1, ITU-R Recommendation 643- 1 (Dusseldorf, Germany), 1990.

APPENDIX: COMMUNICATION SYSTEM PERFORMANCE MODEL

The Communication System Performance Model (CSPM) program creates detailed shaded or contour plots of basic transmission loss, field strength, power density, available power, or signal-to-interference ratios from one or more transmitters in a given geographical area. CSPM allows the user to select the propagation model desired for predictions. The default model is the Institute for Telecommunication Sciences Irregular Terrain Model (ITM) in the point-to-point mode. The model chosen by the user determines path loss along radials of about one degree azimuthal intervals around each transmitter. The ITM is applicable to analyze mobile, broadcast, or radar coverage and interference problems in the 20-MHz to 20-GHz band. The model uses the U.S. Geological Survey 3-arc second terrain database and the Defense Mapping Agency terrain database. These databases provide an elevation point approximately every 90 m. The model also uses the 1990 U.S. Census information and frequently updated FCC databases.

CSPM calculates path losses in a user-defined geographic area. This area is divided into a grid of up to 200 x 200 points for a maximum number of calculated values of 40,000. These path losses are used in the generation of a plot and are converted to the desired output type (e. g., field strength and power) at plot time. The user either imports station information directly from the FCC database or hand enters information about the station. This information includes: transmitter location, power, antenna pattern, tower height, gains and losses of the system, and desired contours of signal coverage. The model plots the desired contours of signal strength and determines the number of households and population that lie within the specified contours. CSPM plots can be combined to produce predicted area coverage of a group of stations. Each cell value of the 200 x 200 grid is set to the maximum signal strength from the group of stations. A sample of the summary of input data is shown in the following table.

Communications System Performance Model Input Summary

21 Nov 95 - 15:43:52

Process Filename: CS000Nov2195E.ques

- 1) Model: Point-to-point irregular terrain model
- 2) Output option: Field intensity
- 3) Length units: English (mi and ft)
- 4) Service application: Broadcast
- 5) Results option: Mail only
 - FAX number: 000-000-0000
- 6) Location variability: 50.00 %
- 7) Time availability: 50.00 %
- 8) Situation variability: 50.00 %
- 10) Frequency: 89.30 MHz
- 11) Polarization: Vertical
- 12) Conductivity: .005 S/m
- 13) Dielectric constant: 15.00
- 14) Climate zone: Continental temperate
- 20) Transmitter name: WRFG
- 21) Transmitter location:

| Latitude | | | Longitude |
|----------|-------------|---------|-------------|
| Deg N | | | Deg W |
| 33.7489 | 33,44,56.00 | 84.4072 | 84,24,26.00 |
- 22) Xmtr site elevation: 309.70 m 1016.00 ft
- 23) Xmtr ant ht AMSL: 361.00 m 1184.38 ft
- 23) Xmtr ant ht AGL: 51.33 m 168.41 ft
- 24) Transmitter radiation option: ERP
- 24) Effective radiated power: 24500.00 W
 - Effective isotropic radiated power: 40196.90 W
- 30) Transmitter ant horiz pattern: Omnidirectional
- 32) Transmitter ant vert pattern: Omnidirectional
- 40) Rcvr ant ht above ground: 9.10 m 29.86 ft
- 56) Corporate name: ITS-TA Services
- 57) Color option: Color
- 58) Scale option: No Scale
- 59) Quality option: High
- 60) Plot name: Atlanta, GA
- 62) Plot center:

| Latitude | | | Longitude |
|----------|-------------|---------|-------------|
| Deg N | | | Deg W |
| 33.7489 | 33,44,56.00 | 84.4072 | 84,24,26.00 |
- 63) Plot size: 350.00 km 217.48 mi
- 64) Plot Roads option: No Roads
- 66) Field intensity contour levels:
 - 1) 54.00 dBuV/m
 - 2) 74.00 dBuV/m
- 66) Contour legend label: Field Intensity (dBuV/m)
- 66) Contour labels and colors:

| Contour levels | Labels | Colors |
|----------------------|--------------------|--------|
| 1 Less than 54.00 | Less than 54.00 | Blue |
| 2 54.00 to 74.00 | 54.0000 to 74.00 | Green |
| 3 Greater than 74.00 | Greater than 74.00 | Clear |
- 67) Political boundaries: County and State
- 68) Landmarks : None

BIBLIOGRAPHIC DATA SHEET

| | | | |
|---|--|---|----------------------------|
| 1 PUBLICATION NO 97-335 | | 2 Gov't Accession No | 3 Recipient's Accession No |
| 4. TITLE AND SUBTITLE FM Subcarrier Corridor Assessment for the Intelligent Transportation System | | 5 Publication Date January 1997 | |
| | | 6 Performing Organization Code NTIA/ITS | |
| 7. AUTHOR(S) Robert O. DeBolt and Nicholas DeMinco | | 9 Project/Task/Work Unit No. | |
| 8 PERFORMING ORGANIZATION NAME AND ADDRESS National Telecommunications and Information Administration Institute for Telecommunication Sciences 125 Broadway Boulder, CO 80303 | | 10. Contract/Grant No | |
| | | 12 Type of Report and Period Covered | |
| 11 Sponsoring Organization Name and Address Federal Highway Administration IVHS Turner-Fairbank Highway Center, Rm T-201 6300 Georgetown Pike McLean, VA 22101-2296 | | 13 | |
| | | 14 SUPPLEMENTARY NOTES | |
| 15 ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.) This report documents the assessment of FM subcarrier performance for ITS applications in three areas of interest in the United States. These areas are: 1) The Interstate 95 corridor from Richmond, Virginia, to Portland, Maine; 2) The Midwest corridor from Gary, Indiana, to Chicago, Illinois, and Milwaukee, Wisconsin, along Interstates 80, 90, and 94; and 3) The Atlanta, Georgia, Metropolitan Area. This study indicates that subcarrier systems of carefully chosen FM stations can provide good performance for ITS applications. | | | |
| 16 Key Words (Alphabetical order, separated by semicolons) FM subcarrier; Intelligent Transportation System; ITS; IVHS | | | |
| 17 AVAILABILITY STATEMENT <input type="checkbox"/> UNLIMITED <input checked="" type="checkbox"/> FOR OFFICIAL DISTRIBUTION | | 18 Security Class (This report) Unclassified | 20 Number of pages 30 |
| | | 19 Security Class. (This page) Unclassified | 21 Price |

NTIA FORMAL PUBLICATION SERIES

NTIA CONTRACTOR REPORT

Information generated under an NTIA contract or grant and considered an important contribution to existing knowledge.

NTIA HANDBOOK

Information pertaining to technical procedures, reference and data guides, and formal user's manuals that are expected to be pertinent for a long time.

NTIA MONOGRAPH

A scholarly, professionally oriented publication dealing with state-of-the-art research or an authoritative treatment of a broad area. A monograph is expected to have a long lifespan.

NTIA REPORT

Important contributions to existing knowledge but of less breadth than a monograph, such as results of completed projects and major activities, specific major accomplishments, or NTIA-coordinated activities.

NTIA RESTRICTED REPORT

Contributions that fit the NTIA Report classification but that are limited in distribution because of national security classification or Departmental constraints. This material receives full review and quality control equivalent to the open-literature report series.

NTIA SPECIAL PUBLICATION

Information derived from or of value to NTIA activities such as conference proceedings, bibliographies, selected speeches, course and instructional materials, and directories.

SPONSOR-ISSUED REPORTS

NTIA authors occasionally produce reports issued under an other-agency sponsor's cover. These reports generally embody the criteria of the NTIA Report series.

For information about NTIA publications, contact the ITS Technical Publications Office at 325 Broadway, Boulder, CO, 80303 Tel. (303) 497-3572 or e-mail shaw@its.blrdoc.gov.

This report is for sale by the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22767, Tel. (703) 487-4650.